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Spatial priming in visual search: Memory for body-centred information.

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Abstract

Spatial priming allows memory for target locations to be evaluated, whereby when a target appears in the same location across trials participants become more efficient at locating it and consequently their search times decrease. Previously, we reported priming effects when the location of a target was repeated with respect to the participant's body but not when it was repeated relative to their eye position; therefore, suggesting that body-centred information is available after a delay of at least a few seconds (Ball, Smith, Ellison, & Schenk, 2010). However, we were unable to rule out the possibility that stable allocentric cues within the room may have contributed to the priming effects that we observed. In this current study we introduced a condition where, despite participants moving to a new location between trials, their position relative to the target was maintained. This movement disrupted any potential room-based cues about the target location. While we replicated our previous finding of priming when the location of the target was repeated relative to the viewer when no movement was required, we also found robust priming effects when participants moved to a new location in between trials. Thus, we provide clear evidence that in our spatial priming task the location of the target was being coded in a body-centred reference frame and that this information is available after a delay.

Keywords

egocentric; frames of reference; spatial memory; conjunction search; priming.

1. Introduction

When we consider the location of an object we can use different frames of reference. If we relate the location of the object to our own body, or a specific part of our body; for example, the pen is to the left of my hand, we are said to be using an egocentric frame of reference. Conversely, we may wish to describe the location of an object with regard to other objects or landmarks in the visual array; for example, the pen is to the right of the cup. In this instance the reference frame is allocentric (Burgess et al. 2004; Witt et al. 2008). Therefore, having both a reference direction (to the left) and a reference object (the viewer, the cup) are necessary in defining an object's location (Mou et al. 2008).

While egocentric frames of reference are used in defining the locations of objects, they have a greater role when it comes to interacting with these objects, that is, when we want to reach forward and pick up a cup for example. To successfully perform any motor action the subject must know the spatial relationship between the position of their effector and the target object: to pick up a cup you need to know the position of the cup's handle in relation to your hand as this determines the direction of your approach and what hand you will use. Accordingly, Milner and Goodale (1993) argue that egocentric representations support visuomotor control. It is argued that this type of information rapidly becomes redundant as representations need to be continuously updated to take account of movement on behalf of the viewer and/or object (Milner and Goodale 1993; Westwood et al. 2003; Mou et al. 2004; Milner and Goodale 2006). As such there is believed to be no value in storing the representations once the motor action has been performed. Likewise, both the degraded visuomotor abilities of patients with visual agnosia and the improved visuomotor performance in patients with optic ataxia after a delay support the notion that dorsal stream information is highly transient (Goodale et al. 1994; Milner et al. 2001; Himmelbach and Karnath 2005; Milner and Goodale 2006). Similarly, while visual illusions have little effect on

visuomotor actions performed in real time, they do affect visuomotor performance after a delay, thus mirroring the effects to perceptual performance observed in real time (Aglioti et al. 1995; Haffenden and Goodale 1998; Vishton et al. 1999; Westwood and Goodale 2003). It is thought that after a delay it is the ventral stream as opposed to the dorsal stream that provides the visual information for motor control.

In previous studies we used between-trial priming to investigate allocentric and egocentric frames of reference. Between-trial priming refers to how the prior presentation of a stimulus affects the processing speed for subsequent presentations of the same stimulus; for example, when either the colour of the target stimulus or the location of the target are repeated, search times become faster (Maljkovic and Nakayama 1994; Maljkovic and Nakayama 1996; Huang et al. 2004; Kristjansson et al. 2005; Geyer et al. 2007). Thus, priming is indicative of some form of memory for the information that is presented in either the trial directly preceding the current trial or a number of trials previously (Shore and Klein 2001). With regards to location priming, we demonstrated that allocentric priming (i.e. the location of the target relative to a landmark is repeated) is effective but not as effective as egocentric priming (i.e. the location relative to the observer is repeated, Ball et al. 2009). We then went on to evaluate which specific egocentric frame of reference was responsible for driving the priming effects. In comparing two egocentric conditions it was found that while repeating the location of a target relative to the observer's body led to significant reductions in search times across trial sequences, repeating the location of a target relative to the fixation cross, and thus relative to the position of the observer's eye, did not have a consistent effect on search times. Furthermore, there was no difference between the priming effects in the body-centred condition and those in the combined body and eye-centred condition. From these observations we concluded that the most relevant frame of reference was the body (Ball et al. 2010).

However, the interpretation of this last study was somewhat complicated by a potential confound. In the body-centred condition while the location of the target remained the same relative to the observer's body it also remained the same relative to the room, and thus the features in it. One might therefore argue that in this condition participants may have used allocentric cues (i.e. some landmark within the room) to code the location of the target. For this reason our conclusion that body-centred priming is effective remains open to criticism. Therefore, it was the aim of the present study to examine whether allocentric coding might account for the priming effects found in our "body-centred" condition. This was achieved by examining and comparing priming effects in two different "body-centred" conditions. The first condition was called *egocentric-stay* and was a replication of the body-centred condition used in Ball et al. (2010). In this condition the location of the target remained the same relative to the body and the room across trials. This condition thus offered possibly both egocentric and allocentric cues. Our second, and new, condition was called *egocentric-move*. In this condition participants were required to move to a new position within the room between trials. This meant that while the location of the target remained the same relative to the observer's body across trials, owing to the observer's movement, its location relative to the room changed. The egocentric-move condition effectively ensured that any potential allocentric cues related to landmarks within the room were rendered ineffective, and thus the observer's body was the only constant frame of reference. We predicted that if participants previously relied on allocentric cues (i.e. landmarks within the room) to code the position of the repeated target location in our so-called "body-centred" condition, they should no longer show any reliable priming effects in the egocentric-move condition. Conversely, if participants are coding the location of the target relative to their bodies, priming effects should be observed in both the egocentric-stay and egocentric-move conditions. Requiring participants to move in between trials increases the minimum period of time between the

presentation of two consecutive search arrays relative to the inter-trial intervals used previously. Combining this increase in inter-trial interval with the ability of our paradigm to measure spatial priming effects over the course of five trials, we are also to provide some information about the time course of memory for egocentric locations.

2. Method

2.1. Participants

Twenty naïve participants (3 male) from Durham University received course credit for taking part in this experiment (age range 18 – 34 years, mean age 22.7). Ethical approval was obtained from the Psychology Research Ethics Committee at Durham University and participants gave informed consent. Participants all had normal or corrected-to-normal vision.

2.2 Stimuli

Each trial consisted of two sets of stimuli. During the first part of a trial a letter was presented and participants had to report its identity. The font size of the letter was such that participants could only recognise its identity if they foveated it. The purpose of this was to ensure that participants looked at the fixation cross at the beginning of the trial and did not linger at the location of the previous target. To obtain the ideal font size we determined the smallest font size that each participant could read at the adopted observer distance. The font sizes used varied between 10 and 16 (corresponding to visual angles 0.3° ($2\pi/1200$) vertically and horizontally, and 0.4° ($2\pi/900$) vertically and horizontally respectively). For each participant the smallest font size they could read when fixating on it was established prior to the experimental trials: 13 participants used font size 10; 5 used font size 12; 2 used font size 16.

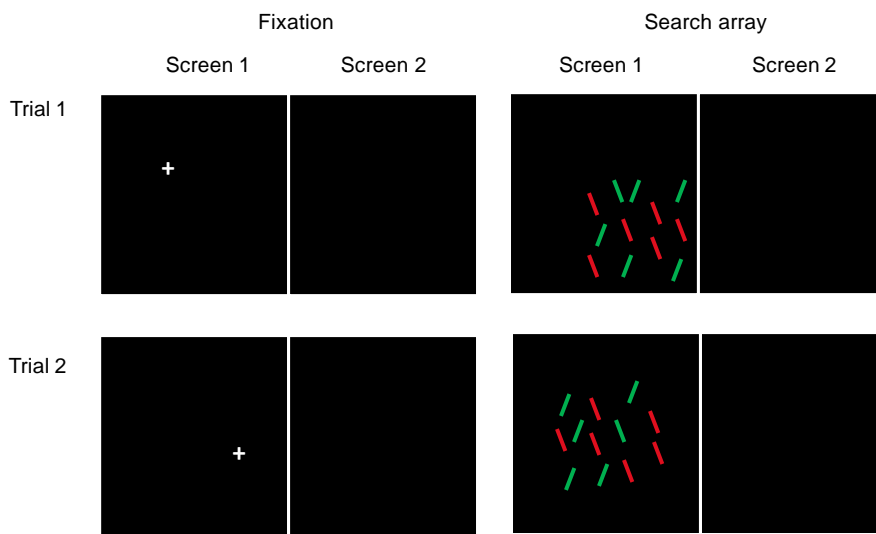
During the second part of a trial a search array was presented. The search arrays consisted of red and green lines on black backgrounds, where the target line was a green backslash (oriented at -20° from vertical) and distractors were a combination of green forward slashes (oriented at 20° from vertical) and red backslashes (see Figures 1a and 2a). Each search array consisted of 12 lines: in target present trials there were 11 distractors (6 red backslashes and 5 green forward slashes) and one target, and in target absent trials there were

12 distractors (6 red backslashes and 6 green forward slashes); thus, there was an equal number of red and green items in the present and absent search arrays.

The stimuli were presented onto a blank wall using two projectors. The two screens were of equal size and located side by side, and the stimuli were projected onto only one of these screens at any one time. Participants were required to stand 290 cm from the wall as this distance ensured that participants were able to move efficiently between the two screens without blocking the projected image. Two standing positions were used, the locations of which were marked on the floor. The set-up was designed so that the standing position for each screen corresponded to the centre of that screen. The search arrays measured 14° ($2\pi/25.7$) vertically and 15° ($2\pi/24$) horizontally and these were placed onto black backgrounds so that the whole image measured 30° ($2\pi/12$) vertically and 40° ($2\pi/9$) horizontally. The luminance of the black background was 6.7 candelas per square metre (cd/m^2), while the stimuli lines were 10.6 cd/m^2 . The experiment was completed in a semi-lit room with the level of lighting such that the edges of the projected image were not discernable from the wall. This setup was used to minimise the availability of other stable visual cues, such as the edge of the projected image, as potential points of reference.

There were two priming conditions: *egocentric-stay* and *egocentric-move*. In both priming conditions the location of the target was positioned relative to the observer's body but at different positions relative to the fixation cross as the location of the fixation cross was randomised across trials. In the *egocentric-stay* condition (see Figure 1) participants remained standing in front of one of the screens for all the trials of a sequence, whereas in the *egocentric-move* condition participants were required to move between the two screens after each trial in a sequence (see Figure 2).

(a) Egocentric – stay condition



(b) Egocentric – stay trial procedure

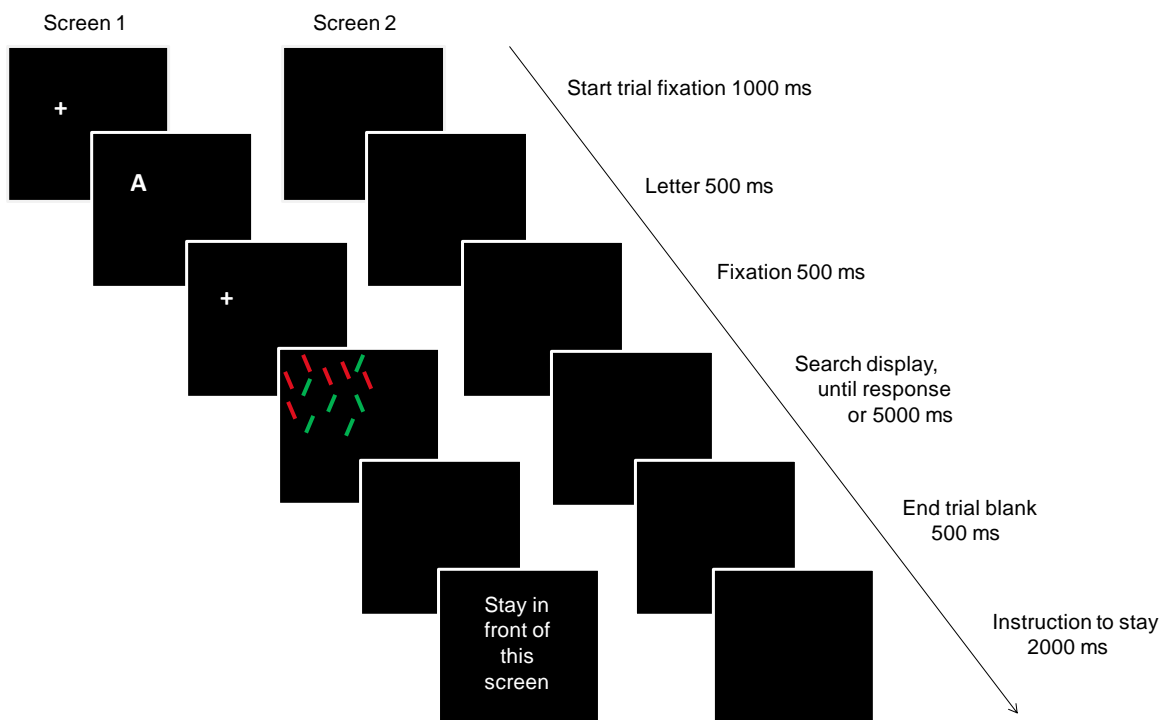
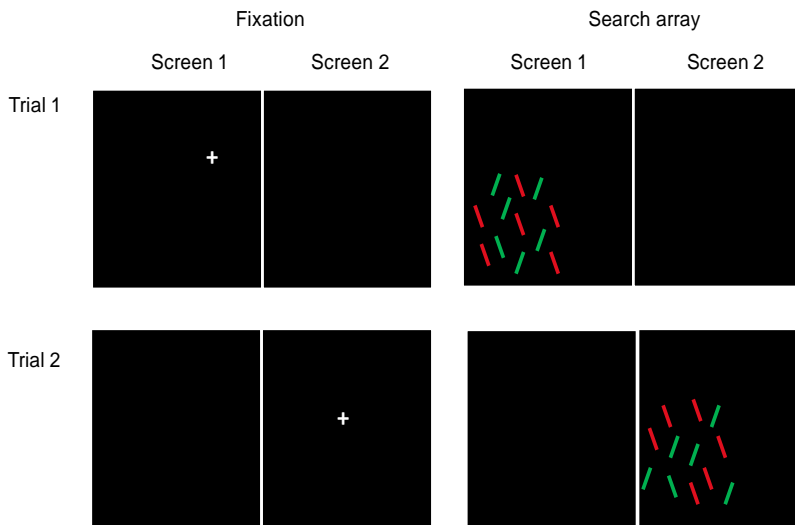


Fig. 1a The egocentric-stay condition. The target stimulus is the green backslash. In trial 1 and trial 2 the target is in the centre of the screen 1 but it occupies a different location relative to the fixation cross. All trials in a stay sequence are presented on the same screen.

Fig. 1b The sequence and timing of an egocentric-stay trial. After the instruction to stay is presented for 2000 ms the next trial automatically started.

(a) Egocentric – move condition



(b) Egocentric – move trial procedure

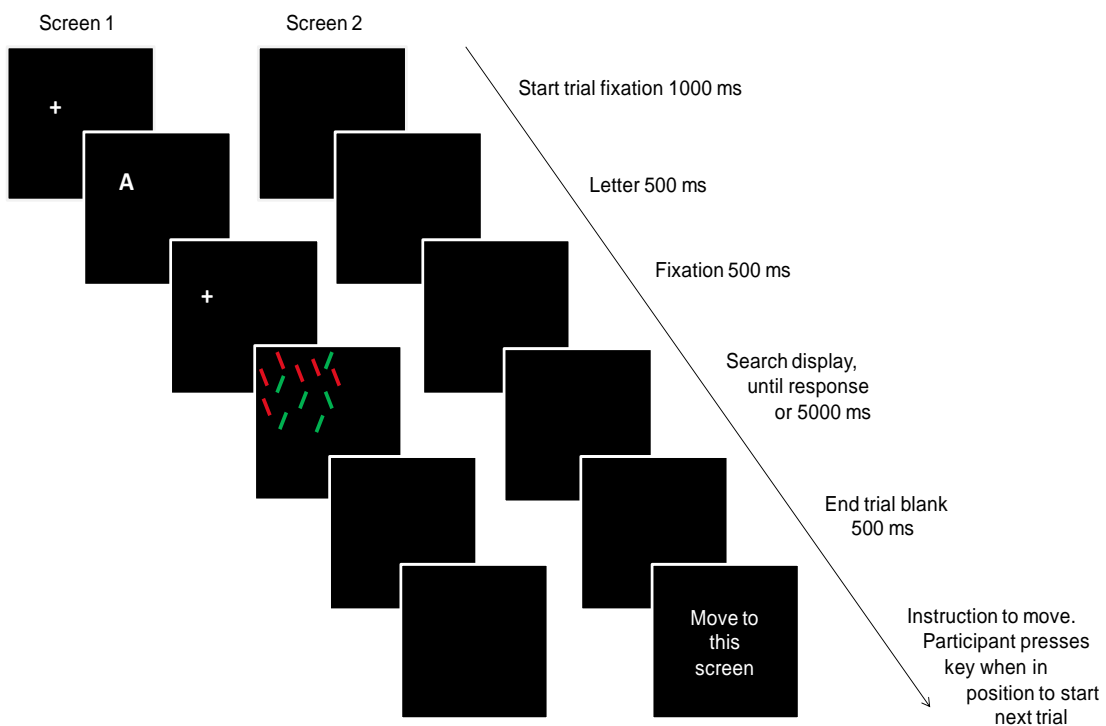


Fig. 2a The egocentric-move condition. The target stimulus is the green backslash. While trials 1 and 2 are presented on different screens the target has the same location within the screen. There is no relationship between the location of the target and the fixation cross. Participants alternate between screens on every trial in a move sequence.

Fig. 2b The sequence and timing of an egocentric-move trial. The subsequent trial is presented on screen 2.

2.3 Procedure

At the beginning of each trial a fixation cross was presented at a random location for 1000 ms. This was replaced with a letter (randomly chosen from a set of 5; presentation duration of 500 ms). Participants had to report this letter to the experimenter. The fixation cross was then re-presented for 500 ms. Next the search display was presented and participants had to decide whether the target line was present in the display and make a key press response accordingly. Participants were instructed to respond as accurately and as quickly as possible and they were not given any feedback about whether they had responded correctly. Once participants had made their response the projected image went blank for 500 ms before the next trial was initiated. A screen instructing participants whether they were required to move to the other screen (egocentric-move condition) or stay in front of the same screen (egocentric-stay condition) for the next trial was presented. If the instruction was to move, participants moved to the new location and pressed a button to indicate when they were in the correct position. This button press started the next trial. In piloting the experiment it was found that moving from one screen to the other took approximately 2 seconds. In the case of a stay-instruction, the next trial was initiated automatically; however, initiation of the next trial was delayed by 2000 ms to ensure that the inter-trial intervals for trials with stay-instruction and move-instruction were roughly equivalent. Therefore, there was a minimum of 4500 ms between the presentations of two consecutive search arrays. The timing information for a trial is shown in Figures 1b and 2b for stay and move trials respectively.

The target stimulus was present in 71% of trials. To induce position-priming, we designed sequences of trials whereby a given target position was used 5 times within a given sequence. Interspersed within a sequence were also 2 target absent trials, thus each sequence consisted of 7 trials. The order of the target present and target absent trials was randomised across sequences. For each priming condition there were 20 different sequences, with a new

target position being used for each sequence, making a total of 140 trials per priming condition (100 target present and 40 target absent).

The experimental trials were divided into four blocks. Each block contained five sequences of move trials and five sequences of stay trials (the five sequences/35 trials of each priming condition were grouped together). Both the order of the priming conditions within a block and the order of the blocks were randomised across participants. The whole experiment took approximately 45 minutes to complete and participants were given breaks in between block of trials.

2.4. Data Analysis

The accuracy of letter reporting was recorded during the experimental trials and was 99.8% across all participants, indicating that participants fixated correctly at the beginning of each trial. Trials where the participant failed to report the letter correctly were not included in the analysis; this resulted in the exclusion of 10 out of 5600 trials. All analyses are concerned with participants' reaction times to decide whether the target stimulus was present or absent in the search array. Incorrect answers (3.8 % of trials) and outliers (responses with reaction times more than two standard deviations above or below the mean, 4.6 % of correct trials) were removed. All data were tested for normality using the Shapiro-Wilk statistic; the data were normal unless otherwise stated. Inferential statistics used a significance level of $p < .05$, except when a Bonferonni correction was applied to adjust the alpha-level for multiple comparisons.

3. Results

3.1 Accuracy

Participants were highly accurate in their responding to the visual search stimuli (target present trials 97.8% correct, target absent trials 93.2% correct). There was no difference in accuracy for trials in the first (95.6%) and second half of the experiment (95.5%, $p = .840$, Wilcoxon Signed Ranks test, data could not be normalised) suggesting that performance was not measurably affected by fatigue. Accuracy was the same in the egocentric-move condition and the egocentric-stay condition (95.5% correct, $p = .614$). Search times to target absent trials ($M = 861.77$, $SD = 192.5$) were significantly slower than search times to target present trials ($M = 710.60$, $SD = 143.6$), $t(19) = 5.66$; $p < .05$. This was observed in both priming conditions (egocentric-move: present trials $M = 732.22$, $SD =$

146.6, absent trials $M = 890.55$, $SD = 191.9$; egocentric-stay: present $M = 689.00$, $SD = 143.0$, absent $M = 832.99$, $SD = 219.5$).

3.2 Immediate priming effects

Figure 3 compares the search times to the first two target present trials of a sequence when they directly followed one another, that is, when there were no intervening target absent trials. A 2 x 2 repeated measured ANOVA with the factors Priming Condition (egocentric-move, egocentric-stay) and Repetition (first present trial, second present trial) revealed a non significant main effect of Priming Condition ($p = .088$); a statistically significant main effect of Repetition, $F(1,19) = 18.54$; $p < .05$, such that search times were faster on the second presentation of a target position; and a non significant Repetition by Priming Condition interaction ($p = .443$). Although no significant Repetition by Priming Condition interaction was found, we still wanted to examine whether a significant priming effect could be found for both priming conditions. Two 2-tailed t-tests confirmed that the difference in search times between the first presentation and second presentation of a target location was significant in both priming conditions: egocentric-move: $t(19) = 2.61$; $p < .025$, with a mean reduction of 33.40 ms ($SD = 57.3$); and egocentric-stay: $t(19) = 3.31$; $p < .025$, with a mean reduction of 49.05 ms ($SD = 66.2$).

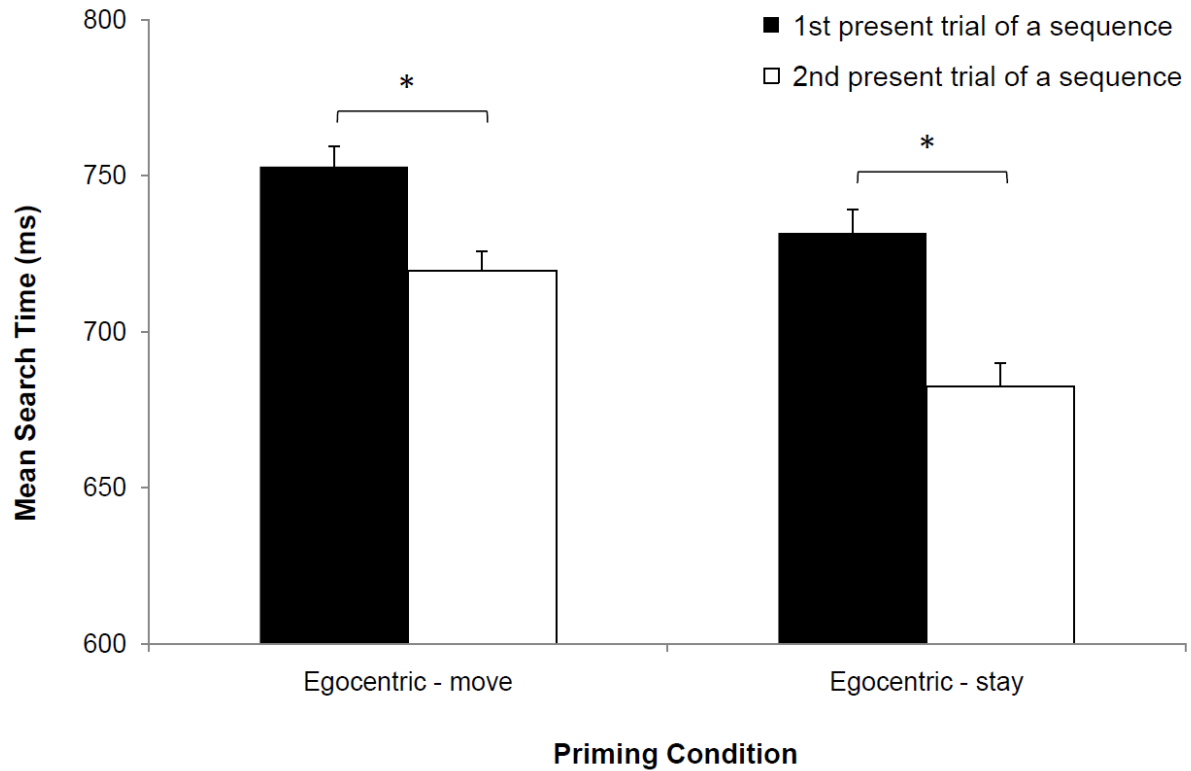


Fig. 3 Search times to the first two target present trials of a sequence when they directly followed each other. Error bars represent the within-subjects standard error of the mean. * denotes significant difference at $p < .025$ (Bonferroni correction applied).

3.3 Cumulative priming effects

Within each sequence of trials the target stimulus was at a given position five times. Search times to non-primed trials (1st trials in a sequence, $M = 752.72$, $SD = 146.2$) were significantly slower than those to primed trials (trials 2 - 4 in a sequence, $M = 700.36$, $SD = 144.3$), $t(19) = 8.96$; $p < .05$. This difference indicates priming of target locations and was observed in both conditions (egocentric-move: non-primed trials $M = 758.75$, $SD = 139.9$, primed trials $M = 725.17$, $SD = 149.6$; egocentric-stay: non-primed trials $M = 746.69$, $SD = 161.1$, primed trials $M = 675.54$, $SD = 141.3$).

Figure 4 plots the search times to the five presentations of a target position for both priming conditions. Search time data were subjected to a 2 x 5 repeated measures ANOVA with the factors Priming Condition (egocentric-move, egocentric-stay) and Presentation

Number (1 - 5). This analysis revealed a significant main effect of Priming Condition, $F(1,19) = 29.04$; $p < .05$; a significant main effect of Presentation Number, $F(4,76) = 16.36$; $p < .05$; and a non significant Presentation Number by Priming Condition interaction ($p = .068$).

To follow up the main effect of Priming Condition, search times to all present trials in the egocentric-move condition were compared to those in the egocentric-stay condition (2-tailed t-test). Participants' responses were faster in the egocentric-stay priming condition ($M = 689.77$, $SD = 144.1$) compared to the egocentric-move priming condition ($M = 731.89$, $SD = 146.7$), $t(19) = 5.39$; $p < .05$.

With regards to the main effect of Presentation Number, it can be seen from Figure 4 that search times decreased as the number of presentations of a target location increased. This pattern was observed in both priming conditions. As the Priming Condition by Presentation Number interaction was not statistically significant no other follow up analyses were needed. However, to see whether there were more subtle differences between the two priming conditions, we directly compared the search times between the first and fifth target present trial directly for both priming conditions, using 2-tailed t-tests. In the egocentric-stay condition there was a mean reduction of 92.32 ms ($SD = 73.9$) between the first and fifth presentation of a target location which was statistically significant, $t(19) = 5.59$; $p < .025$. In the egocentric-move condition there was a mean reduction of 44.30 ms ($SD = 49.2$) between the first and fifth presentation, again statistically significant, $t(19) = 4.02$; $p < .025$. It should be noted that the trend of greater cumulative priming in the egocentric-stay condition cannot be explained by different initial search times: there is no difference in search times to the first target present trials of a sequence for the priming conditions (egocentric-move condition: $M = 758.75$, $SD = 139.9$; egocentric-stay condition: $M = 746.69$, $SD = 161.1$, $p = .476$).

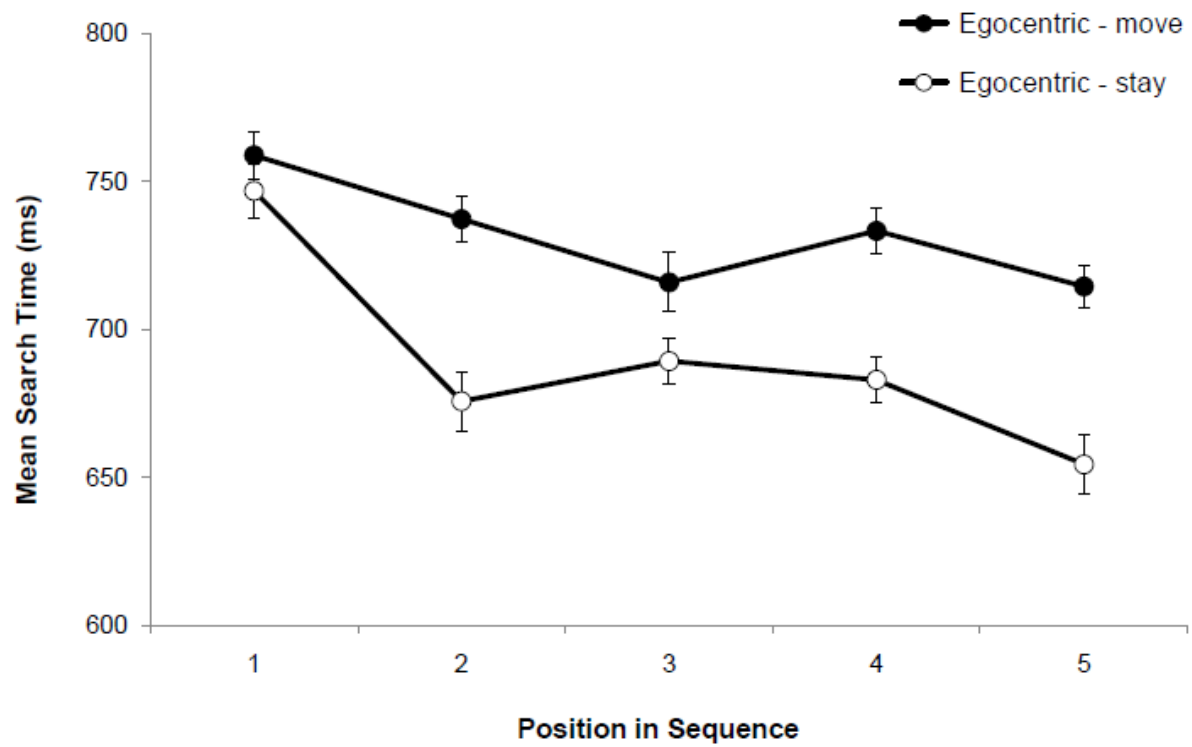


Fig. 4 Search times to target present trials as a function of their position in the sequence. Error bars represent the within-subjects standard error of the mean.

4. Discussion

The current study follows our earlier studies in which we suggested that egocentric priming is effective and that egocentric representations can persist for several seconds (Ball et al. 2009; Ball et al. 2010). However, in our previous studies it was not possible to entirely exclude the possibility that participants also used some unspecified allocentric landmarks in what we considered to be an egocentric condition. We rectified this problem in the current study by including a new egocentric condition whereby participants were required to move between trials to a new position within the room. In this egocentric-move condition the experimental setup was such that while the target occupied the same location relative to the observer, its location within the room changed between the two presentations. This also allowed us to compare the priming effect in this egocentric-move condition with our previous “body-centred” condition where participants were not required to move (egocentric-stay), and thus provided an opportunity to evaluate the possible contribution of room-related landmarks in coding target location.

We observed significant priming effects both when participants stayed in the same location and when they were required to move in between trials. This movement meant that any other potential frames of reference, such as a visual cue in the room that we were not aware of, were disrupted. Therefore, it is concluded that the location of the target was being coded relative to the observer’s body. While the difference between the amounts of priming in the two conditions is not significant, there is clearly a trend for greater cumulative priming in the egocentric-stay condition compared to the egocentric-move condition. This suggests that in the egocentric-stay condition participants may have used some room-related information that we were not aware of; for example, the distance to the door or the window. However, this does not detract from our observations of significant cumulative priming effects in the egocentric-move condition where any cues that the room provided were

disrupted with participant movement. Furthermore, these priming effects were observed in spite of moving between locations after each trial which is likely to have caused a degree of distraction.

The current experiment is able to provide further information about the time scale over which egocentric information can persist. The introduction of the movement element increased the minimum inter-trial interval between two consecutive search arrays from 2500 ms in the previous experiment to 4500 ms here. We found that the priming effects built up over the five target present trials of a sequence, which were interspersed with target absent trials. Therefore, in view of the extended period of time between trials, and the observation of significant cumulative priming effects, it is now possible to argue that egocentric representations can be stored for more than just a couple of seconds.

The finding here that body-centred information can persist and influence search performance in subsequent trials is consistent with findings from topographical memory research, and specifically those that have evaluated the ability for egocentric representations to be updated. The studies involving whole body movements found that recognition performance was better when the viewpoint of the testing phase was the same as the viewpoint of learning phase (Diwadkar and McNamara 1997; Christou and Buelthoff 1999; Shelton and McNamara 2004). Furthermore, Finlay, Motes, and Kozhevnikov (2007) observed a steady decrease in recognition performance (response times became longer and less accurate) as the distance between the learnt view and test view increased. Taken together with the observations of cumulative priming in this current study there is evidence that egocentric representations can persist for more than four seconds.

The conclusion here that egocentric information can persist for several seconds is in conflict with the observations of delayed visuomotor performance. The visuomotor performance of patient D.F. who has visual agnosia following ventral stream damage is

impaired after a period of delay (Goodale et al. 1994) and her performance at making memory guided eye movements is less accurate compared to when she makes stimulus-driven eye movements (Rossit et al. 2010). The degradation in D.F.'s performance has been explained by the assumption that, since egocentric information cannot persist, her performance after a delay relies upon allocentric information from the ventral stream, which is damaged (Milner and Goodale 1995; Milner and Goodale 2006). Furthermore, Cohen, Cross, Tunik, Grafton, and Culham (2009) report that the application of TMS to either ventral and dorsal stream areas affects delayed visuomotor performance. This therefore confirms that the ventral stream is involved to some degree in the execution of delayed movements. However, if egocentric information can persist, as suggested here, why is the ventral stream more critical for delayed performance than for non-delayed performance, as shown by D.F. being more impaired in delayed tasks compared to non-delayed tasks?

It is known that the primary source of sensory information for the perception of our body's position, namely receptors in our muscles, joints, and tendons, produce transient signals and it is plausible to assume that the reliability of this information diminishes rapidly over time (Carlson 2001; Riemann and Lephart 2002). Therefore, it is possible that in order to maintain a sense of our body's position more sustained and persistent information, including visual information from the ventral stream, may be needed. This is supported by a recent study from Zaehle et al. (2007) who used functional imaging to examine the brain correlates of spatial perception. Participants in their study had to make egocentric judgements; for example, deciding whether the target shape was on their right or not. They found activations in the inferior temporal gyrus, the calcarine sulcus, and the superior occipital gyrus. This suggests that the ventral stream is not just critical for allocentric (Schenk 2006) but also for egocentric coding. On the basis of these assumptions we could explain why persistent egocentric representations are found in healthy participants, and this set of

assumptions can also explain why egocentric representations are no longer persistent when the ventral stream is damaged. According to this account, ventral-stream input is required to maintain stable egocentric representations and thus the ventral-stream makes an important contribution to visuomotor control (for a more detailed discussion of this issue see Schenk 2010; Schenk and McIntosh 2010).

Egocentric representations are most often thought of with regard to motor tasks (Westwood et al. 2001; Witt et al. 2008; Schenk and McIntosh 2010). Therefore, how is using a perceptual task here to investigate the temporal persistence of egocentric information relevant to the real time visuomotor hypothesis? Milner and Goodale (1993) argue that visuomotor processing relies on egocentric coding. Egocentric coding defines the location of an object relative to the body but as the position of the body is constantly changing, it does not make sense to store the egocentric information. As such it should be assumed that egocentric representations are transient irrespective of the task demands. We are not able to conclude that the representations underlying visuomotor processing are not sustained but we are able to challenge the justification of the real-time visuomotor hypothesis that after delay egocentric information is not available.

Finally, it should be noted that the sample consisted of considerably more female than male participants. While there is some evidence to suggest a gender difference in spatial recognition abilities (for example, Lawton 2001; Kim et al. 2007), Dabbs et al. (1998) found no difference between the memory of object locations in males and females, and likewise performance on a spatial priming task did not differ between genders (Koshino et al. 2000). It seems therefore unlikely that a more balanced sample would have yielded a substantially different result.

In conclusion, our study has demonstrated that while unidentified allocentric landmarks may have accounted for some of the priming effects observed in our previous

studies, they certainly do not account for all priming effects found in egocentric priming conditions. We report robust egocentric priming effects in a condition where participants had to move between trials, thus removing possible allocentric cues. Moreover, we showed that such egocentric information can persist for more than four seconds. This confirms our previous view that in healthy participants egocentric information is not as transient as claimed by proponents of the perception-action model.

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